Very high-luminosity polarized proton operation

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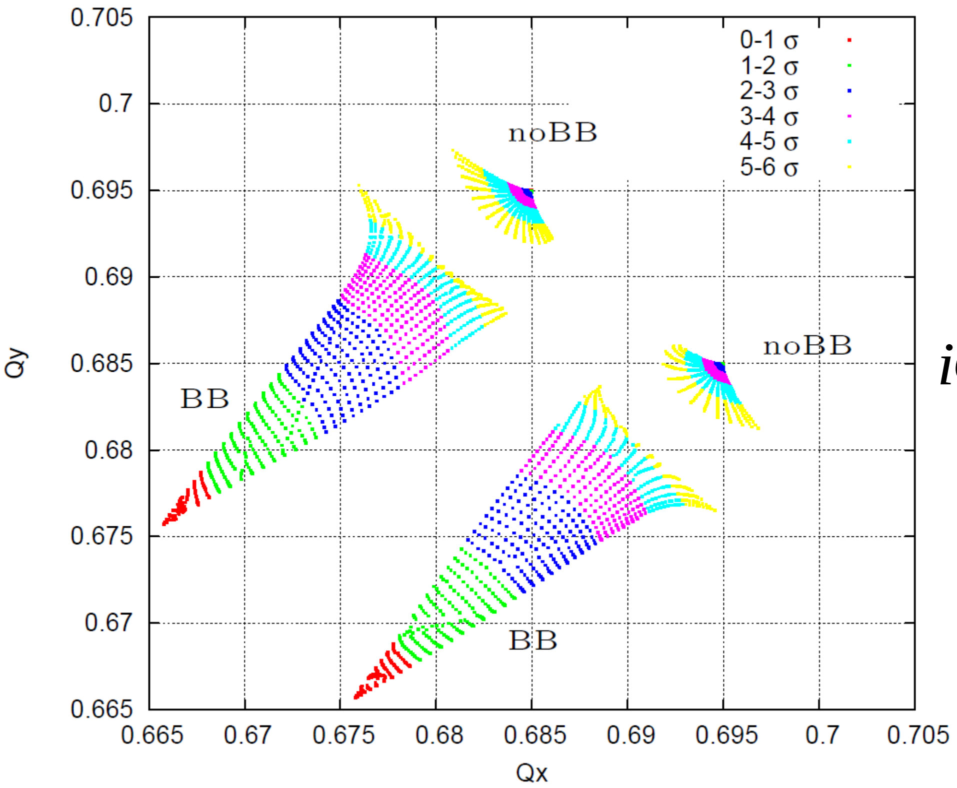
Thanks to Wolfram Fischer, Vladimir Litvinenko and Thomas Roser

Outline:

1) Basic problem
2) Scaling laws for short bunches
3) Numerical results for long bunches



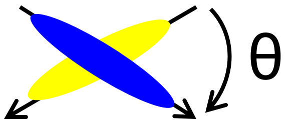
Beam-beam force shifts and
Spreads the betatron tune
Figure from Luo et. al. C-A/AP/310

$$iQ_{spin} + jQ_x + kQ_y + lQ_{synch} = m$$

Basic Problem

- Fundamental trade off between luminosity and beam-beam tune shift
- For $\sigma_\perp << \sigma_s << \beta^*$ the system looks like two colliding ellipsoids
- Luminosity is the event rate divided by the cross section

$$L = \frac{f_{coll} N_{bunch}^2}{4\pi\sigma_\perp^2 \sqrt{1 + (\theta\sigma_s / 2\sigma_\perp)^2}}$$



- Beam-Beam tune shift is due to defocusing driven by electromagnetic field of other bunch

$$\Delta Q_x + \Delta Q_y = \frac{r_c \beta^* N_{bunch}}{2\pi\gamma\sigma_\perp^2 \sqrt{1 + (\theta\sigma_s / 2\sigma_\perp)^2}} \le 0.01 / IP$$

Combining gives $$L = \frac{f_{coll} N_{bunch} \gamma}{2 r_c \beta^*} \left(\Delta Q_x + \Delta Q_y \right)$$

Increase N_{bunch} or reduce β^* to increase luminosity

With significant crossing angle all events are close to the IP

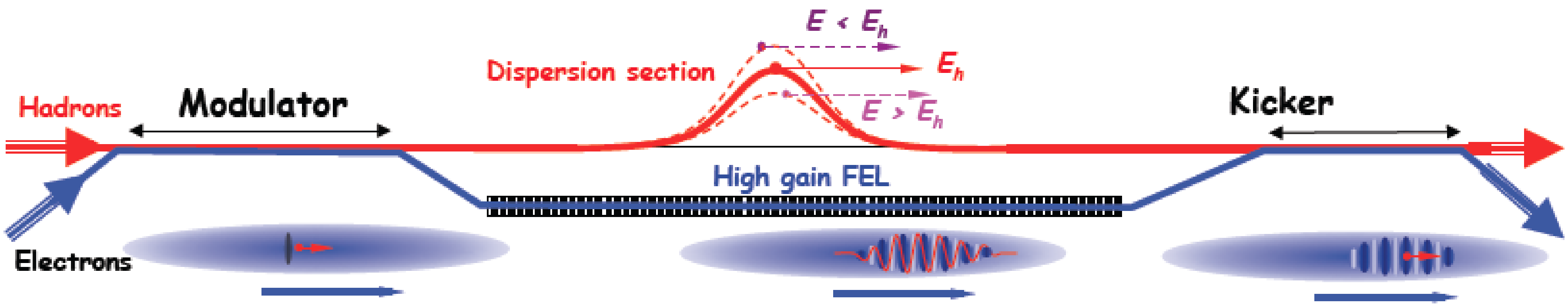
Coherent electron cooling

Reducing β^* increases the beam size in the triplets

$$< x^2 >= \varepsilon\beta(s) = \varepsilon\left(\beta^* + \frac{s^2}{\beta^*}\right)$$

no mystery, just ballistic transport

Can't scrape in triplets, so reducing β^* requires reducing ε



Proton imprints its density on electrons via Debye shielding

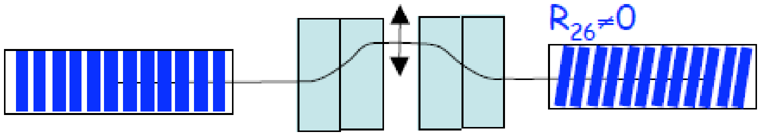
Electron density modulations greatly enhanced in FEL,
 protons slip with respect to ideal energy

Shifted proton kicked by space charge force on electrons

Transverse cooling

- Transverse cooling can be obtained by using coupling with longitudinal motion via transverse dispersion
- Sharing of cooling decrements is similar to sum of decrements theorem for synchrotron radiation damping, I.e. decrement longitudinal cooling can be split into appropriate portions to cool both transversely and longitudinally: $J_s+J_h+J_v=J_{CEC}$
- Vertical (better to say the second eigen mode) cooling is coming from t-coupling

Non-achromatic chicane installed at the exit of the FEL before the kicker section turns the fronts of the charged planes



$$\delta z = -R_{26} \cdot x$$

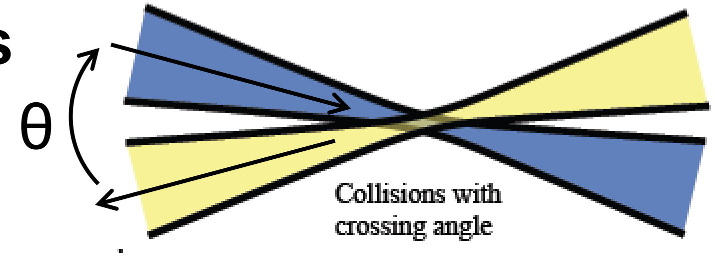
$$\Delta \mathbf{E} = -eZ^2 \cdot E_o \cdot L_2 \cdot$$

$$\sin\left\{k\left(D\frac{\mathbf{E}-\mathbf{E}_o}{\mathbf{E}_o} + R_{16}x' - R_{26}x + R_{36}y' + R_{46}y\right)\right\};$$

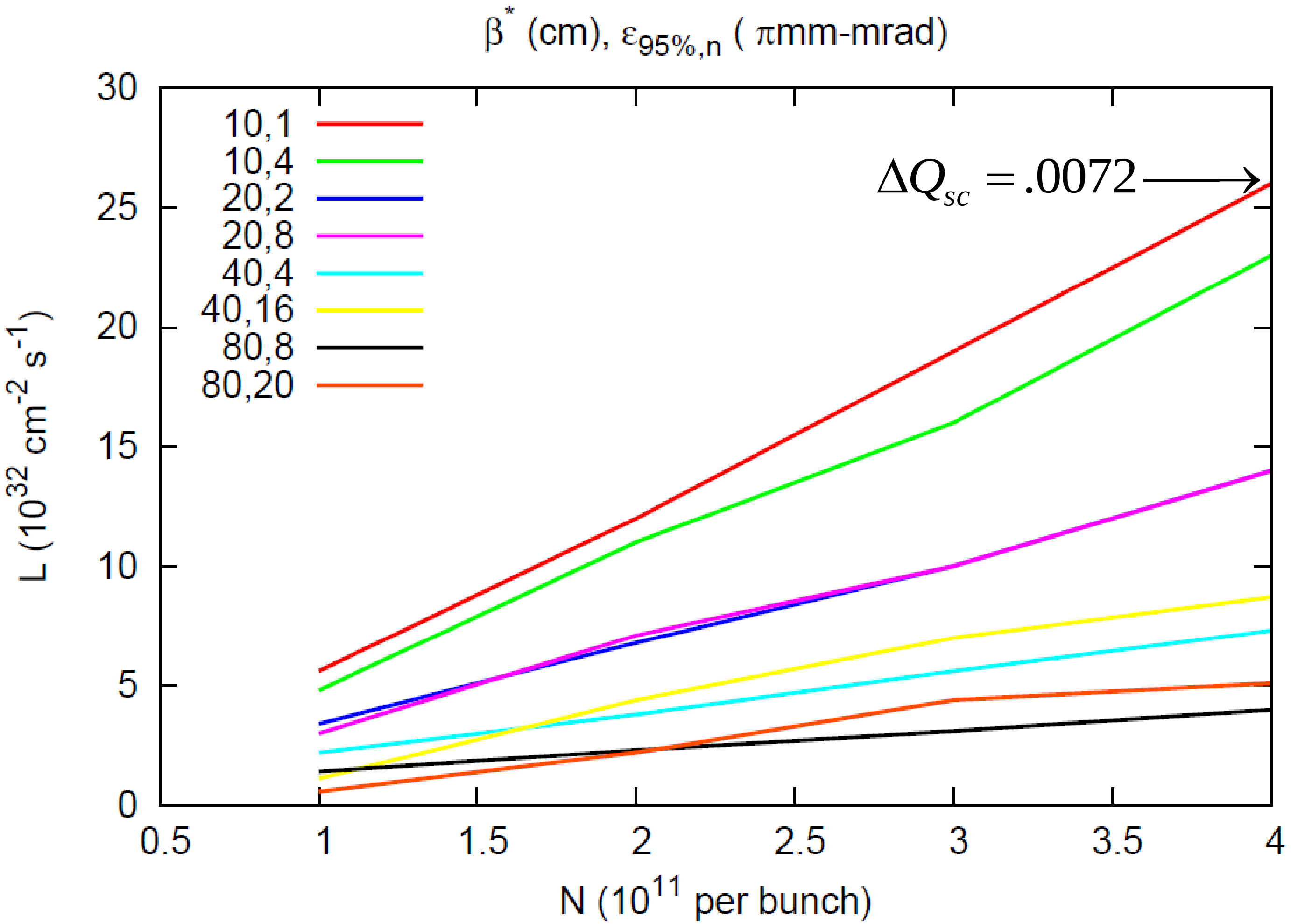
$$\Delta x = -\eta \cdot eZ^2 \cdot E_o \cdot L_2 \cdot kR_{26}x + ...$$

$$J_x(\max) \cong \frac{\eta\sigma_\varepsilon}{\sigma_x} J_{CEC}$$

Calculations with realistic parameters



Strategy is to set β^*, ε, N_{bunch} and increase θ until $\Delta Q_y = 0.01$



Mainly scales with N_{bunch} / β^*

$\theta < 3$mrad

Summary

Luminosity is related to beam-beam tune shift via

$$L \approx \frac{f_{coll}\gamma N_{bunch}}{2r_c\beta^*}\Delta Q_{bb,tot}$$

Since $\Delta Q_{bb,tot}$ is limited we can increase N_{bunch} or reduce β^* .

Reducing β^* while keeping manageable beam size in the triplets requires reduced emittance, hence beam cooling.

With adequate beam cooling, $4\text{x}10^{11}$ protons per bunch, $\Delta Q_{bb,tot}$ =0.015 and 10cm β^* we can reach

$$L = 3\times 10^{33} cm^{-2} s^{-1}$$